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Observation on rapid physiological color change in Giant tree frog *Rhacophorus smaragdinus* (Blyth, 1852) from Namdapha Tiger Reserve, Arunachal Pradesh, India

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Abstract

Many poikilotherms have the ability to change body color for homeostatic regulation, conspecific communication or predator deterrence. Physiological color change is a rapid, reversible mode of color change regulated by neuromuscular or neuroendocrine system and has been observed in several anuran species. Here we report the occurrence of physiological color change in the tree frog *Rhacophorus smaragdinus* (Blyth, 1852) (Amphibia, Anura, Rhacophoridae) for the first time from Namdapha Tiger Reserve, Arunachal Pradesh, India. Probable proximate causes of the behavior are discussed along with an overview of physiological color change in species of the family Rhacophoridae and nature of color change observed.

Key Words

anuran behavior, reversible color change, camouflage, physiological stress, thermoregulation, Rhacophoridae, *Rhacophorus maximus*, *Theloderma*, *Raorchestes*, *Pseudophilautus*

Introduction

The ability to change body coloration is widespread among poikilotherms and is displayed by a diverse group of animals including cephalopods (Norman 2000, Hanlon 2007), crustaceans (Thurman 1988), insects (Hinton and Jarman 1972, Filshie et al. 1975), fishes (Kodric-Brown 1998), amphibians (King et al. 1994, Garcia and Sih 2003), and reptiles (Cooper and Greenberg 1992).

Based on the mechanism involved, color change can be of two types: (i) morphological color change, which involves changes in morphology and density of pigment-containing cells (chromatophores) in the dermis and occurs at relatively longer time scales spanning from days to months (Sugimoto 2002), and (ii) physiological color change, which involves dispersion or aggregation of pigment granules within chromatophores and occurs at shorter time scales ranging from milliseconds to hours (Thurman 1988, Nordlund et al. 1998). Physiological color change is regulated by neuromuscular or neuroendocrine system and; hence, is rapid and reversible (Sumner 1940, Fujii 2000). Depending upon the taxon under consideration, color change may serve one or a combination of following adaptive functions: (i) predator avoidance (through crypsis or aposematism; Kats and van Dragt 1986), (ii) conspecific communication (Stuart-Fox and Moussalli 2008), and (iii) homeostatic function (thermoregulation or hydroregulation; King et al. 1994). The phenomenon is well studied in anurans especially in tree frogs of the family Hylidae (Kats and van Dragt 1986, Kang et al. 2016). Although similar in body form and its arboreal habitat, little is known about color changing ability in Afro-Asian tree frogs of the family Rhacophoridae (Cott 1934). Here we report the occurrence of rapid physiological color change in the rhacophorid, *Rhacophorus smaragdinus* (Fig. 1) for the first time.

The species formerly known as *Rhacophorus maximus* Günther, 1858 was recently assigned to the nomen *Rhacophorus smaragdinus* after recovery of type specimens of *Polypedates smaragdinus* Blyth, 1852 from ZSI collections (Ohler and Deuti 2018). Type locality of *P. smaragdinus* is "Naga hills, Assam", India. *R. smaragdinus* (Blyth, 1852) is characterized by its large size, green dorsal coloration, brown on flanks and complete, uniform greyish webbing between fingers and toes (Anders and Rai 2002). Distribution of the species ranges from Nepal to India, Southern China, Western Thailand, Northern Bangladesh, Myanmar, Laos, Cambodia and northern Vietnam. In India, it is recorded from the states of West Bengal, Sikkim, Arunachal Pradesh, Nagaland, Assam, Meghalaya, and Manipur (Ohler and Deuti 2018). It is a crepuscular species and inhabits lowland and submontane moist evergreen forests.

Observation

On 12 October 2016, at 20:00 hrs, a single adult female of *R. smaragdinus* (SVL.=12.6 cm) was observed perched on a tree branch at about 3 m height from the ground near Deban (27.4971°N, 96.3911°E ; 361 m asl.) in Namdapha Tiger Reserve, Changlang district, Arunachal Pradesh, India. The individual was identified as an adult female owing to its large size and absence of nuptial pads and vocal sac (male secondary sexual characters). The habitat was characterized by lowland tropical evergreen rainforest formation with dense canopy cover. The color of the individual was noted to be lime green, but as soon as it was placed on a tree trunk with brownish bark for taking photographs, the dorsal coloration started to change. In a span of few minutes, the color changed from green to dull brown, reducing the contrast with background and making the animal less conspicuous. As we left the individual undisturbed, it started changing its color back to green (Fig. 2). It took approximately 25 minutes for the frog to change its color from brown back to green, although it would have taken still more time for it to regain its original lime green coloration (as observed when the individual was captured). The initial color change from green to brown was faster than the color reversal but the time taken was not accurately quantified.

Discussion

It is unlikely that the response had any homeostatic function, as ambient temperature conditions before and after the capture of individual were not significantly different. The possibility of conspecific communication can also be ruled out as individuals of the same species were neither heard nor seen in close proximity. It is most likely that the disturbance caused by handling had elicited a predator deterrence response in the individual causing it to rapidly change dorsal body color to match with the background. Background matching by rapid color change can be particularly advantageous for species living in heterogeneous environments and frequently moving between different kinds of substrates, to conceal itself from visual predators (Kang et al. 2016). Alternatively, color change could be a by-product of hormone release associated with other processes such as amplexus or in this case physiological stress and may not serve any particular adaptive function

Figure 1. *Rhacophorus smaragdinus* (Blyth, 1852) in its habitat.

Figure 2. Sequence of color change from brown to green in *Rhacophorus smaragdinus* (Blyth, 1852).

Table 1. List of rhacophorid species (apart from *Rhacophorus* sp.) exhibiting rapid physiological color change and nature of color change observed.

Species	Nature of color change	Literature source
Chiromantis xerampelina Peters, 1854	Skin coloration varies from dark brown to white presumably for thermoregulation	Shoemaker et al. 1989
Gracixalus tianlinensis Chen, Bei, Liao, Zhou, & Mo, 2018	Dorsal coloration varies from brown to beige or dark brown; coloration of throat varies from grey to brown	Chen et al. 2018
Kurixalus eiffingeri (Boettger, 1895)	Dorsal coloration changed from uniform grey or brown to greenish while the individual was on a greenish substrate	Kuramoto and Wang 1987
Mercurana myristicapalustris Abraham, Pyron, Ansil, Zachariah, & Zachariah, 2013	Dorsal coloration changed from rusty brown to dull brown resembling the color of forest floor, where the individuals (in amplexus) just moved to	Abraham et al. 2013
Polypedates maculatus (Gray, 1830)	Individuals placed in sunlight turned light in color (light grey, tan or yellow) whereas those placed in shaded area turned darker in color	Lillywhite et al. 1998
Pseudophilautus femoralis (Günther, 1864)	Dorsal coloration changes from green to yellow; always green during capture (at night)	Inger et al. 1984
Pseudophilautus viridis (Manamendra-Arachchi & Pethiyagoda, 2005)	Dorsal body coloration changes from dull green to brownish (presumably) to match with soil color	Bopage 2015
Pseudophilautus wynaadensis (Jerdon, 1853)	Dorsal coloration changes from reddish brown at night to pale grey or brownish grey during daytime	Kuramoto and Joshy 2003
Raorchestes gryllus (Smith, 1924)	Dorsal coloration varies between different combinations of black, grey, brown, red, green and yellow depending on physiological condition of the individual	Orlov et al. 2012
Raorchestes luteolus (Kuramoto & Joshy, 2003)	Body coloration changes from pale yellow at night to brownish during daytime	Kuramoto and Joshy 2003
Raorchestes tuberohumerus (Kuramoto & Joshy, 2003)	Dorsal coloration becomes darker and body markings more prominent during daytime	Kuramoto and Joshy 2003
Theloderma auratum Poyarkov, Kropachev, Gogoleva, & Orlov, 2018	Dorsal coloration light beige to cream nocturnally but turns darker during daytime; coloration varies with respect to diel period and microhabitat conditions	Poyarkov et al. 2018
Theloderma licin McLeod & Norhayati, 2007	Dorsal coloration changes from solid white to white mottled with brown on handling; coloration varies in response to stress and presumably with respect to diel period and microhabitat conditions	McLeod and Norhayati 2007
Theloderma nebulosum Rowley, Le, Hoang, Dau, & Cao, 2011	Coloration changes from lighter to darker shade. Dorsal pattern more distinct at night.	Rowley et al. 2011
Theloderma palliatum Rowley, Le, Hoang, Dau, & Cao, 2011	Dorsal coloration changes from brown patches on white background in the morning to a less contrasting brown on dull white at night	Rowley et al. 2011
Theloderma vietnamense Poyarkov, Orlov, Moiseeva, Pawangkhanant, Ruangsuwan, Vassilieva, Galoyan, Nguyen, & Gogoleva, 2015	Dorsal coloration changes from greyish brown or dark beige at night to dark chocolate brown during daytime; color of belly is dark brown with purple tint nocturnally which changes to darker blackish brown with violet tint diurnally; pigmentation of parts of skin varies in response to stress, diel period and microhabitat conditions	Poyarkov et al. 2015

as such (Kindermann et al. 2014). *Rhacophorus lateralis* Boulenger, 1883 from India and *Rhacophorus prominanus* Smith, 1924 from Malaysia exhibit rapid physiological color change, presumably in response to stress (Bennet et al. 1998, Molur and Molur 2010, Marcus 2017). Bennet et al. (1998) observed calling *R. lateralis* with dark brown dorsum turn pale green when handled while Molur and Molur (2010) noted calling individuals with bright green dorsum and neon green dots turn bright brown with coffee colored dots on handling. *R. prominanus* observed on a dark substrate changed dorsal coloration from bright green to dark green-brown in less than 5 seconds. The behavior was suspected to be elicited by the disturbance caused by observers (Marcus 2017). Ostroshabov et al. (2013) noted *Rhacophorus hoanglienensis* Orlov, Lathrop, Murphy, and Ho, 2001 and *Rhacophorus viridimaculatus* Ostro-

shabov, Orlov, and Nguyen, 2013 from Northern Vietnam to exhibit varying dorsal colors and patterns depending on physiological condition although the proximate cause of the behavior was not discussed.

Besides *Rhacophorus*, rapid physiological color change is also known to occur in species belonging to the genera *Chiromantis* Peters, 1854; *Gracixalus* Delorme, Dubois, Grosjean, and Ohler, 2005; *Kurixalus* Ye, Fei, and Dubois, 1999; *Mercurana* Abraham, Pyron, Ansil, Zachariah, and Zachariah, 2013; *Polypedates* Tschudi, 1838; *Pseudophilautus* Laurent, 1943; *Raorchestes* Biju, Shouche, Dubois, Dutta, and Bossuyt, 2010 and *Theloderma* Tschudi, 1838 of family Rhacophoridae (Table 1). While one must be careful in drawing inferences regarding adaptive function of the behavior from these studies which are mostly based on opportunistic observations, diel period (Inger et al. 1984, Kuramoto and Joshy 2003, Rowley et al. 2011, Poyarkov et al. 2015, Poyarkov et al. 2018), microhabititat conditions (Kuramoto and Wang 1987, Abraham et al. 2013), ambient temperature (Shoemaker et al. 1989, Lillywhite et al. 1998) and physiological condition of the animal (Bennet et al. 1998, McLeod and Norhayati 2007, Molur and Molur 2010, Orlov et al. 2012, Marcus 2017) seems to play a significant role in eliciting the behavior in Rhacophorids. Some Rhacophorids such as *Rhacophorus malabaricus* Jerdon, 1870 are known to exhibit ontogenetic color change (Biju et al. 2013), which in most cases is a form of morphological color change (Booth 1990), the discussion of which is beyond the scope of this manuscript. Our understanding regarding color-changing ability, factors influencing the behavior and its adaptive function in anurans is currently limited by a dearth of natural history observations and carefully designed experimental studies.

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References

Abraham RK, Pyron RA, Ansil BR, Zachariah A, Zachariah A (2013) Two novel genera and one new species of treefrog (Anura: Rhacophoridae) highlight cryptic diversity in the Western Ghats of India. Zootaxa 3640(2): 177–189. https://doi.org/10.11646/zootaxa.3640.2.3

Anders C, Rai KR (2002) *Rhacophorus maximus* Günther, 1859. In: Schleich HH, Kästle W (Eds) Amphibians and reptiles of Nepal – Biology, Systematics, Field Guide. Koeltz Scientific Books, Koenigstein, 337–340.

Bennet D, Hampson K, Sanders K, Anderson M (1998) Frogs of Coorg, Karnataka, India. Final Report of the Aberdeen University Western Ghats Project, 14–30.

Biju SD, Kamei RG, Mahony S, Thomas A, Garg S, Sircar G, Suyesh R (2013) Taxonomic review of the tree frog genus *Rhacophorus* from the Western Ghats, India (Anura: Rhacophoridae), with description of ontogenetic colour changes and reproductive behaviour. Zootaxa 3636(2): 257–289. https://doi.org/10.11646/zootaxa.3636.2.3

Booth CL (1990) Evolutionary significance of ontogenetic colour change in animals. Biological Journal of the Linnean Society 40(2): 125–163. https://doi.org/10.1111/j.1095-8312.1990.tb01973.x

Bopage MM (2015) Ovipositional behaviour of *Pseudophilautus viridis*, Manamendra-arachchi and Petiyagoda, 2005 (Amphibia: Rhacophoridae) from Sri Lanka. https://doi.org/10.13140/RG.2.1.2631.5686

Chen W, Bei Y, Liao X, Zhou S, Mo Y (2018) A new species of *Gracixalus* (Anura: Rhacophoridae) from West Guangxi, China. Asian Herpetological Research 9(2): 74–84. https://doi.org/10.16373/j.cnki.ahr.170085

Cooper WE, Greenberg N (1992) Reptilian coloration and behavior. In: Gans C, Crews D (Eds) Hormones, Brain and Behavior – Biology of the Reptilia. Vol. 18. The University of Chicago Press, Chicago and London, 298–422.

Cott HB (1934) On the ecology of *Hyla arborea* var. *meridionalis* in Gran Canaria, with special reference to predatory habits considered in relation to the protective adaptations of insects. Journal of Zoology 104(2): 311–331. https://doi.org/10.1111/j.1469-7998.1934.tb07755.x

Filshie BK, Day MF, Mercer EH (1975) Colour and colour change in the grasshopper, *Kosciuscola tristis*. Journal of Insect Physiology 21(11): 1763–1770. https://doi.org/10.1016/0022-1910(75)90238-3

Fujii R (2000) The regulation of motile activity in fish chromatophores. Pigment Cell Research 13(5): 300–319. https://doi.org/10.1034/j.1600-0749.2000.130502.x

Garcia TS, Sih A (2003) Color change and color-dependent behavior in response to predation risk in the salamander sister species *Ambystoma barbouri* and *Ambystoma texanum*. Oecologia 137(1): 131–139. https://doi.org/10.1007/s00442-003-1314-4

Hanlon R (2007) Cephalopod dynamic camouflage. Current Biology 17(11): 400–404. https://doi.org/10.1016/j.cub.2007.03.034

Hinton HE, Jarman GM (1972) Physiological colour change in the Hercules beetle. Nature 238(5360): 160. https://doi.org/10.1038/238160a0

Inger RF, Shaffer HB, Koshy M, Bakde R (1984) A report on a collection of amphibians and reptiles from the Ponmudi, Kerala, South India. Journal of the Bombay Natural History Society 81(2): 406–427. http://biostor.org/reference/153661

Kang C, Kim YE, Jang Y (2016) Colour and pattern change against visually heterogeneous backgrounds in the tree frog *Hyla japonica*. Scientific Reports 6: 22601. https://doi.org/10.1038/srep22601

Kats LB, van Dragt RG (1986) Background color-matching in the spring peeper, *Hyla crucifer*. Copeia 1986(1): 109–115. https://doi.org/10.2307/1444895

Kindermann C, Narayan EJ, Hero JM (2014) The neuro-hormonal control of rapid dynamic skin colour change in an amphibian during amplexus. PloS ONE 9(12): e114120. https://doi.org/10.1371/journal.pone.0114120

King RB, Hauff S, Phillips JB (1994) Physiological color change in the green treefrog: responses to background brightness and temperature. Copeia 1994(2): 422–432. https://doi.org/10.2307/1446990

Kodric-Brown A (1998) Sexual dichromatism and temporary color changes in the reproduction of fishes. American Zoologist 38(1): 70–81. https://doi.org/10.1093/icb/38.1.70

Kuramoto M, Wang CS (1987) A new rhacophorid treefrog from Taiwan, with comparisons to *Chirixalus eiffingeri* (Anura, Rhacophoridae). Copeia 1987(4): 931–942. https://doi.org/10.2307/1445556

Kuramoto M, Joshy SH (2003) Two new species of the genus *Philautus* (Anura: Rhacophoridae) from the Western Ghats, southwestern India. Current Herpetology 22(2): 51–60. https://doi.org/10.5358/hsj.22.51

Lillywhite HB, Mittal AK, Garg TK, Das I (1998) Basking behavior, sweating and thermal ecology of the Indian tree frog, *Polypedates maculatus*. Journal of Herpetology 32(2): 169–175. https://doi.org/10.2307/1565293

Marcus LEE (2017) Rapid colour change in the Malayan flying frog *Rhacophorus prominanus* at Fraser's Hill, Peninsular Malaysia. Southeast Asia Vertebrate Records 2017: 12–13. https://www.ecologyasia.com/pdf/2017/seavr2017-006(p012-013).pdf

McLeod DS, Norhayati A (2007) A new species of *Theloderma* (Anura: Rhacophoridae) from southern Thailand and peninsular Malaysia. Russian Journal of Herpetology 14(1): 65–72. http://rjh.folium.ru/index.php/rjh/article/view/217

Molur S, Molur P (2010) *Rhacophorus lateralis* in Madikeri, Kodagu, Karnataka. Frog Leg 14: 6–7.

Nordlund JJ, Boissy RE, Hearing VJ, King RA, Ortonne JP (1998) The Pigmentary System: Physiology and Pathophysiology. Oxford University Press, New York, 1025 pp. https://trove.nla.gov.au/work/20162151?q&versionId=46517259

Norman MD (2000) Cephalopods, a world guide: Pacific Ocean, Indian Ocean, Red Sea, Atlantic Ocean, Caribbean, Arctic, Antarctic. No. C/594.5 N6: 320 pp. https://www.si.edu/object/siris_sil_611032

Ohler A, Deuti K (2018) *Polypedates smaragdinus* Blyth, 1852-a senior subjective synonym of *Rhacophorus maximus* Günther, 1858. Zootaxa 4375(2): 273–280. https://doi.org/10.11646/zootaxa.4375.2.7

Orlov NL, Poyarkov NA, Vassilieva AB, Ananjeva NB, Nguyen TT, Nguyen NS, Geissler P (2012) Taxonomic notes on rhacophorid frogs (Rhacophorinae: Rhacophoridae: Anura) of southern part of Annamite Mountains (Truong Son, Vietnam), with description of three new species. Russian Journal of Herpetology 19(1): 23–64. http://rjh.folium.ru/index.php/rjh/article/view/457

Ostroshabov AA, Orlov NL, Nguyen TT (2013) Taxonomy of frogs of genus *Rhacophorus* of "hoanglienensis-orlovi" complex. Russian Journal of Herpetology 20(4): 301–324. http://rjh.folium.ru/index.php/rjh/article/view/848

Poyarkov Jr NA, Kropachev II, Gogoleva SS, Orlov NL (2018) A new species of the genus *Theloderma* Tschudi, 1838 (Amphibia: Anura: Rhacophoridae) from Tay Nguyen Plateau, central Vietnam. Zoological Research 39(3): 158–184. https://doi.org/10.24272/j.issn.2095-8137.2018.018

Poyarkov Jr NA, Orlov NL, Moiseeva AV, Pawangkhanant P, Ruangsuwan T, Vassilieva AB, Galoyan EA, Nguyen TT, Gogoleva SS (2015) Sorting out moss frogs: mtDNA data on taxonomic diversity and phylogenetic relationships of the Indochinese species of the genus *Theloderma* (Anura, Rhacophoridae). Russian Journal of Herpetology 22(4): 241–280. http://www.rjh.folium.ru/index.php/rjh/article/view/1011

Rowley JJL, Le DTT, Hoang HD, Dau VQ, Cao TT (2011) Two new species of *Theloderma* (Anura: Rhacophoridae) from Vietnam. Zootaxa 3098(1): 1–20. https://doi.org/10.11646/zootaxa.3098.1.1

Shoemaker VH, Baker MA, Loveridge JP (1989) Effect of water balance on thermoregulation in waterproof frogs (*Chiromantis* and *Phyllomedusa*). Physiological Zoology 62(1): 133–146. https://doi.org/10.1086/physzool.62.1.30160002

Stuart-Fox D, Moussalli A (2008) Selection for social signalling drives the evolution of chameleon colour change. PLoS Biology 6(1): e25. https://doi.org/10.1371/journal.pbio.0060025

Sugimoto M (2002) Morphological color changes in fish: regulation of pigment cell density and morphology. Microscopy Research and Technique 58(6): 496–503. https://doi.org/10.1002/jemt.10168

Sumner FB (1940) Quantitative changes in pigmentation, resulting from visual stimuli in fishes and amphibia. Biological Reviews 15(3): 351–374. https://doi.org/10.1111/j.1469-185X.1940.tb00763.x

Thurman CL (1988) Rhythmic physiological color change in crustacea: a review. Comparative Biochemistry and Physiology Part C: Comparative Pharmacology 91(1): 171–185. https://doi.org/10.1016/0742-8413(88)90184-3